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prove to be more sensitive to explosive shocks than those without swim-bladders, and experiments showed that a half stick of dynamite may be exploded within 3 feet of a small shark, which has no swim-bladder, without producing any apparent injury. This also applies to a lesser degree to such teleosts as lack swim-bladders. Dr. S. C. Ball kindly dissected some of the fishes with swim-bladders which had been killed by the explosions, and found that the swim-bladder had burst, and the tissues were crushed in around it, often breaking the vertebral column of the fish. Moreover, Prof. W. H. Longley, who has had much experience in the use of dynamite, tells me that echinoderms, and crustacea, if not mechanically torn apart, show no apparent ill effects but however move away from the site of the explosion.

It appears, then, that the nervous system of these lower forms is extraordinarily insensitive to shock due to explosion of dynamite, and that the injurious effects of the explosion if present are due to mechanical lacerations of tissues and especially the crushing inward of air-filled cavities. It seems possible, therefore, that the cavities of the middle ear and eustachean tubes may be a source of danger to men standing near exploding shells.

It has been suggested that the sudden reduction in atmospheric pressure in the close proximity of an exploding shell might set free dissolved gases in the blood and elsewhere, thus vacuolating the tissues and producing pressure and other effects upon the nerves; but our experiments with pulsating rings of *Cassiopea* seem to negative this hypothesis for no injurious effects other than those of simple asphyxiation were produced by sudden exhaustion of the air surrounding the animals; and recovery, when replaced in normal sea water, was almost immediate.

These results are in accord with the conclusion of Grasset, Eder, Babinski et Froment, and others that war shock is predominantly a psychic phenomenon, and being hysteria it can be cured by hypnotic suggestion.

## CHEMICAL DIFFERENTIATION OF THE CENTRAL NERVOUS SYSTEM IN INVERTEBRATES

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The selective action of drugs for certain tissues forms the basis of the science of pharmacology. The action of such substances as strychnine in increasing the sensitivity of the sensory-motor junctions of the spinal cord is definitely known. In a more general way the selective affinity of caffein, camphor and atropin for specific parts of the vertebrate central nervous system has been established.

As an instance of the application of this method to the study of the nervous systems of other forms, Baglioni[1] has attempted an analysis of the cephalopod ganglia by means of strychnine and phenol. Strychnine was found to be specific for the cerebral ganglia and phenol for the mantle ganglia.

The writer recently has found that freshly hatched squid (Loligo pealii) furnish excellent material for demonstrating reactions of the type under discussion. These little animals show a delicate sensitivity to the action of the substance used. Their response to stimulation is easily demonstrable in the muscular convulsions of tentacles, neck and mantle, and the spasms are in every case, except where specifically inhibited, accompanied by a striking play of the chromatophores. The cephalopod chromatophore is a globular sac containing either yellow, red or brown pigment. At rest these bodies appear as small dark spots, scattered inconspicuously over the surface of the mantle, head and tentacles. Muscle fibers attached radially to the chromatophore control its form. Contraction of these fibers stretches the sac into a sheet, so that the surface of a given chromatophore may be increased a hundred-fold by this mechanism.

The result of strong stimulation, such as mechanical injury or the action of potassium chloride, is a series of clonic spasms of the entire musculature, invariably involving extreme extension of the chromatophores. The play of brilliant color may therefore be used as an indicator of stimulation. If the precaution is taken to view the animals against a white background, the reaction can be followed with the naked eye. Details can be studied with the aid of the low power objective of the microscope.

In carrying out an experiment, a half dozen freshly hatched squid were put into a Syracuse watch glass containing a solution of the substance to be tested. In sufficiently dilute solutions the characteristic effects could be followed for an hour or longer. A strychnine sulfate solution (1: 100,000) maintained the squid in a highly sensitive state for over an hour, so that a slight jar was sufficient to throw the animal into spasms and bring on the play of chromatophores over the entire body.

When put into caffein solution (1: 10,000) juvenile squid show rapid circus movements. The circular character of the course is due to the cramped bending of the neck. The tentacles also show convulsions. At the same time a lively expansion of the chromatophores takes place in the entire head region and solely in this region. Only rarely may the display extend to the mantle.

In sea water one-sixth saturated with camphor gum, the reaction of young squid is exactly the reverse of that in caffein. While the head and tentacles remain passive and their chromatophores closed, the muscular spasms and the play of color take place in the mantle. The fact that the camphor acts directly on the mantle (stellar) ganglia may be demonstrated in the following way. With the stroke of a sharp scalpel sever the head from the body of the squid. In a few seconds the results of mechanical stimulation have abated and both parts are at rest with the chromatophores closed. Now put the two parts of the animal, head and body, into the camphorated sea water. The mantellar region shows muscular convulsions and the brilliant play of chromatophores, while the head and tentacles remain quiescent unless stimulated directly.

Juvenile squid immersed in atropin sulfate solution (1:2500) show abnormally rapid swimming movements, soon followed by failure of locomotion. The animals lie on the bottom of the dish and with the microscope one may see the spasmodic contractions of the tentacles and mantle. There is no play of the chromatophores. This fact distinguishes atropin spasms from those due to strychnine, caffein and camphor. It may be that the failure of the radial muscles of the chromatophores to contract is due to the blocking of the impulses to these muscles. In such a case we would have an analogy in the action of atropin in paralyzing the terminations of the sympathetic in vertebrates.

Crustaceans are far less favorable material for the study of the selective action of drugs. This is undoubtedly in part due to a failure of the substance used to penetrate the tissues. The writer has shown that certain fresh water crustaceans are rendered more sensitive to light by treatment with solutions of strychnine, atropin and caffein.[2] Striking results may also be obtained in marine forms with saturated solutions of camphor gum. Specimens of the hermit crab (Pagurus longicarpus) after a few minutes' immersion in the solution of camphor gum in sea water are seized with tremors at each attempt at locomotion. This is due to the fact that all the appendages are thrown into convulsive trembling movements resembling the symptoms of palsy in human beings. Similar effects may be observed in the marine shrimp (Crangon vulgaris). In this form the thoracic appendages first show tremors, then complete paralysis. The swimmerets are next extended at right angles to the median line of the body and show continuous tremors. At this stage, the animal, when stimulated, invariably swims forward, and is entirely unable to move backward. This is due to the fact that the swimmerets are able to make only the stroke which carries the animal forward. This fact may indicate that camphor acts selectively on the ganglia of the abdominal nerve cord, paralyzing the motor elements which control backward swimming, and rendering more sensitive the nervous elements controlling forward movement. Eventually complete paralysis supervenes.

Further tests were made to determine the character of the action of strychnine, atropin, caffein and camphor on starfish (Asterias), medusa (Gonionemus) and the sea anemone (Metridium). In the case of medusa and sea anemone, atropin alone was an effective reagent in increasing the animal's sensitivity. A sea anemone put into atropin sulfate solution (1:2000) upon stimulation withdraws the tentacles, contracts the sphincter, and spasmodically contracts the longitudinal muscles. The animal does not fully recover the relaxed condition in the atropin solution but revives in a few minutes in a stream of fresh sea water. Specimens of medusa put into atropin sulfate solution (1:2500) contract their tentacles and show continuous activity of the bell with an abnormally high rate of pulsation. Starfish were affected by atropin in the same way as by strychnine, viz: the animals show a strong tendency to bend the rays dorsalward, which is increased by stimulation. Caffein and camphor are not effective in increasing the irritability of starfish.

These results indicate an increased chemical complexity of the central nervous system developing *pari passu* with an increase in morphological complexity. Thus, in the actinian and coelenterate where the diffuse nerve net system obtains, strychnine, caffein and camphor exert no excitatory action. With the development of localized nerve tracts and the beginning of a central nervous system in the asteroids, strychnine, in comparatively high concentrations, produces its characteristic effects. In crustacea and the cephalopod mollusca with their highly developed central nervous systems, the strychnine is, as we should expect, effective in low concentrations. Caffein and camphor act as excitants only where the histological elements of the nervous system are completely elaborated, viz.: in crustacea and the cephalopod mullusca.

Atropine stands in a separate category, since it is effective as a nerve excitant in members of all the classes tested. It would seem, then, that atropine forms a compound with a fundamental constituent of all the nerve cells, while strychnine, caffein and camphor combine with neuronic molecules which are the products of a higher organization.

*Summary.*—As evidence for the chemical differentiation of the central nervous system in invertebrates, it has been shown that, in the cephalopod (Loligo pealii), caffein brings about hyperirritability of the cerebral ganglia, while camphor affects the stellar ganglia alone in the same sense. Atropin causes spasms in the squid, but inhibits the activity of the chromatophores.

Camphor shows a selective action on the central nervous system of the shrimp (Crangon vulgaris) paralyzing the elements which function in backward swimming movements and exciting those controlling forward movement.

Atropin increased the sensitivity of all the forms tested.

[1] Baglioni, S., *Zs. allg. Physiol.*, **5**, 1905, (43–65).

[2] Moore, A. R., *Science, New York*, N. S., **38**, 1913, (131–133).

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# PROOF OF THE MUSCLE TENSION THEORY OF HELIOTROPISM

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That the mechanism by which heliotropic organisms are oriented to light should be identical with that for the orientation to the galvanic current was demanded by the tropism theory developed by Loeb in 1888.[1] The identity of the mechanism in sessile forms was early established by Loeb, while more recently Bancroft[2] has clearly shown that the tenets of the theory hold also in the movements of *Euglena*, which are accomplished in an identical way whether under the influence of light or of the constant current.

It is the aim of this paper to show that the movements of many heliotropic insects under the influence of light are to be explained as forced motions due to the effects of light upon the tension or tonus of the muscles and that in this regard, there exists an exact analogy to the effects of the constant current in the animals investigated.

Loeb and Maxwell[3] showed that when a constant current passed from side to side of *Palæmonetes* the legs on the anodal side were flexed, while those on the cathodal side were extended. With the anode at the anterior end the anterior legs were flexed and the posterior extended. Reversal of the current reversed the condition of tension in these legs and body changes were also induced. The whole response persisted while the current flowed and put the animals in such a condition that any movement forced them toward the anode. Similarly it was shown